SHORT-TERM EFFECT OF STRENGTH TRAINING WITH AND WITHOUT SUPERIMPOSED ELECTRICAL STIMULATION ON MUSCLE STRENGTH AND ANAEROBIC PERFORMANCE. A RANDOMIZED CONTROLLED TRIAL. PART I

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ABSTRACT

Herrero, AJ, Martín, J, Martín, T, Abadía, O, Fernández, B, and García-López, D. Short-term effect of strength training with and without superimposed electrical stimulation on muscle strength and anaerobic performance. A randomized controlled trial. Part I. *J Strength Cond Res* 24(6): 1609–1615, 2010—The purpose of this study was to compare strength training with and without superimposed electromyostimulation (EMS) on muscle strength and anaerobic power. Twenty-eight subjects were assigned to: weight + EMS (ES), weight (VOL), or control group (CG). ES and VOL performed 4 training sessions per week during 4 weeks on a knee extension machine (8 sets; 8 repetitions; 1-second concentric phase from 90° to 0°, 1-second eccentric phase from 0° to 90°, 1-second rest at 90°; 3-minute rest between sets; 70% maximal voluntary contraction). Group ES received EMS in the concentric phase of each action (120 Hz, 400 microseconds). Before training, after training, and 2 weeks after the end of the training (detraining), maximal voluntary contraction, squat jump, countermovement jump (CMJ), countermovement jump with free arms (CMJ_A), and 20-m sprint time were analyzed. After the training period, ES and VOL increased their muscle strength (40.2% and 31.4%, respectively, $p < 0.001$). After the detraining period, this gain remained above baseline values for ES and VOL (49.1% and 24.5%, respectively, $p < 0.001$). Changes in muscle strength between baseline and detraining were higher in ES than in VOL ($p < 0.01$). Anaerobic performance was not affected by training in any group, but percentage change between baseline and after training suggests that the CMJ and CMJ_A with free arms performance were impaired in ES with respect to VOL and CG. Superimposed EMS onto voluntary contractions increases strength more than voluntary training alone; nevertheless, a detraining period should be respected to observe this delayed adaptation. To improve anaerobic power with superimposed EMS, a complementary and specific work such as plyometrics should be carried out.

KEY WORDS maximal voluntary contraction, vertical jump, sprint time, knee extensors, detraining

INTRODUCTION

Over the last 2 decades, research about the use of electromyostimulation (EMS) as a strength training modality has increased substantially (12,25). Different studies have analyzed the chronic effects that EMS evokes over different characteristics of muscle function, the maximum force (isometric or dynamic) being the most assessed. The quadriceps femoris is the most frequently studied muscle (2). In this muscle, the isometric application of EMS alone increased maximum force from 7 to 62% after a training period (25), whereas it produced no positive or not even a negative effect on anaerobic power (13).

Considering anaerobic power, the combination of isometric EMS with plyometric (13,19), basketball (18), skating (4), rugby (1), or volleyball (20) training has been effective to increase jump (1,13,18,19,20) and sprint (4,13) abilities. Because the motor unit recruitment pattern is different under induced EMS contractions (11), it seems necessary to combine EMS with voluntary actions to improve anaerobic performance. This combination can also be done in a concomitant way by using superimposed EMS (the application of an electrical stimulus during a voluntary muscle action). This technique has been shown effective to improve maximal strength (23), and some authors have suggested that it could also be effective in improving

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Table 1. Control group ($n = 10$) interday intraclass correlation coefficients and coefficients of variation for the 3 testing sessions.*†

Variable	ICC	CV (%)
MVC	0.817‡	7.3 ± 6.9
SJ	0.976‡	2.7 ± 1.2
CMJ	0.935‡	4.0 ± 2.5
CMJ$_A$	0.955‡	2.4 ± 2.1
ST	0.861‡	1.2 ± 1.0

*MVC = maximal voluntary contraction; SJ = squat jump; CMJ = countermovement jump; CMJ$_A$ = countermovement jump with free arms; ST = sprint time.

†Values are represented as mean ± *SD*.

‡Significant at $p < 0.001$.

anaerobic power (13,33). However, no study has analyzed the influence of superimposed EMS training and detraining effects on anaerobic performance. Likewise, systematically superimposed EMS has never been compared with concentric action and voluntary training performed at the same intensity. Therefore, the purpose of this study was to compare strength training with and without superimposed EMS on maximal voluntary contraction, vertical jump height, and sprint time (ST). Two groups trained the quadriceps femoris on a knee extension machine with the same load during a 4-week period, and one of them received superposed EMS in the concentric phase. Because EMS supposes a greater metabolic demand than voluntary actions (30), it could be hypothesized that strength gains would be greater in the concomitant group after the training and detraining periods.

Methods

Experimental Approach to the Problem

This is a randomized controlled trial with 2 treatment groups and 1 control group (CG) with repeated-measures outcome assessments over a 6-week period. During the first 4 weeks, 4 training sessions were carried out by each treatment group (Monday, Tuesday, Thursday, and Friday). Each subject was tested on 3 separate occasions: (a) before training (T1), (b) 3–4 days after the completion of the 4-week training period (T2), and (c) 2 weeks after the end of the training period (detraining, T3). Tests were always performed at the same hour of the day and after a standardized 15-minute warm-up that included low-intensity running, several acceleration runs, jumping at a progressively increased intensity, and stretching exercises. The independent variables were the time at which the measurement was taken and treatment group. Dependent variables were maximal isometric voluntary contraction (MVC), squat jump (SJ), countermovement jump (CMJ), countermovement jump with free arms (CMJ$_A$), and ST.

Subjects

Twenty-eight male physical education students volunteered to participate in the study. After a familiarization session with the testing protocols, subjects were randomly assigned to 1 of

Table 2. Muscle strength and anaerobic performance for the treatment and control groups at T1, T2, and T3.*†

		ES ($n = 10$)	VOL ($n = 8$)	CG ($n = 10$)
MVC ($kg \cdot kg^{-1}$)	T1	1.17 ± 0.35	1.27 ± 0.32	1.38 ± 0.30
	T2	1.64 ± 0.47‡	1.66 ± 0.42‡	1.35 ± 0.20
	T3	1.74 ± 0.52‡	1.58 ± 0.47‡	1.36 ± 0.16
SJ (cm)	T1	35.6 ± 5.5	33.0 ± 4.7	31.1 ± 6.3
	T2	34.0 ± 5.5	31.8 ± 4.4	31.4 ± 5.9
	T3	34.3 ± 6.5	33.5 ± 5.3	30.5 ± 5.4
CMJ (cm)	T1	40.6 ± 6.1	39.2 ± 5.1	34.7 ± 5.8
	T2	38.1 ± 6.1	39.1 ± 4.5	34.6 ± 5.4
	T3	38.6 ± 7.3	39.6 ± 4.5	33.4 ± 5.0
CMJ$_A$ (cm)	T1	48.1 ± 6.1	45.3 ± 6.8	42.5 ± 7.2
	T2	44.5 ± 5.9‡	46.2 ± 6.3	42.1 ± 6.5
	T3	45.2 ± 7.0§	47.5 ± 4.3	41.4 ± 6.0
ST (s)	T1	3.07 ± 0.19	3.03 ± 0.11	3.03 ± 0.14
	T2	3.06 ± 0.15	3.07 ± 0.11	3.05 ± 0.14
	T3	3.06 ± 0.17	3.03 ± 0.10	3.03 ± 0.12

*MVC = maximal voluntary contraction; SJ = squat jump; CMJ = countermovement jump; CMJ$_A$ = countermovement jump with free arms; ST = sprint time; ES = weight + electromyostimulation group; VOL = weight group; CG = control group; T1 = before training; T2 = 3–4 days after the completion of the 4-week training period; T3 = 2 weeks after the end of the training period.

†Mean values ± *SD*.

‡,§Significant difference from T1 values ($p < 0.001$ and $p < 0.05$, respectively).

2 treatment groups: weight + EMS (ES, $n = 10$, age 21.4 ± 1.4 years; height 1.76 ± 0.05 m; mass 79.2 ± 10.8 kg); weight (VOL, $n = 8$, age 21.1 ± 1.6 years; height 1.75 ± 0.07 m; mass 77.8 ± 12.0 kg). A CG of 10 subjects did not train and was used to assess the reliability of the observations (CG, $n = 10$, age 20.6 ± 0.6 years; height 1.77 ± 0.02 m; mass 71.6 ± 6.2 kg) (mean ± *SD*). Each subject gave written informed consent to participate, with the risks and benefits of the study carefully explained to them before its initiation. No subject performed professional or amateur sport before or during the experimental phase. In addition, subjects were not allowed to perform any strength or endurance training that would impact the results of the study during this period. The study was conducted according to the Declaration of Helsinki and was approved by the University Committee on Human Research. No subject had previously experienced EMS.

Procedures

Training Protocols. EMS superimposed on weight training. The ES group trained bilaterally on a knee extension machine (Salter Fitness, Tarragona, Spain). Subjects warmed up during 5 minutes with low-frequency EMS (5 Hz). Afterward, subjects performed 8 sets of 10 repetitions with a 3-minute rest between sets. The timing of each repetition was 0.5 seconds of EMS rise time, in which subjects were instructed to tense the muscle keeping the knee angle at 90°; 1 second of maximal EMS applied intensity (Compex Sport-P, Medicompex SA, Ecublens, Switzerland), in which subjects were instructed to perform the concentric phase (from 90° of knee flexion to 0° or complete knee extension); 1 second of eccentric phase (from 0° to 90°); and 1-second resting period (at 90°). The range of motion was constant for all contractions, and the exercise pace was controlled by a metronome (Wittner, Dresden, Germany). The stimulator generated a biphasic symmetrical square wave signal delivered with a frequency of 120 Hz, giving a pulse width of 400 microseconds (13). Three, 2-mm-thick, self-adhesive electrodes were used on each thigh: one negative electrode (10 × 5 cm) was placed on the most proximal part of the quadriceps (about 10 cm below the groin), and 2 positive electrodes (5 × 5 cm) were placed as close as possible to the motor point of the vastus medialis and vastus lateralis muscles. The current level was controlled by the researcher, and it was individually set for each contraction at the maximum tolerated (average tolerated intensity: 60.3 ± 15.3 mA). In each repetition, subjects moved a load equal to the 70% of their MVC, which was obtained in the pretest carried out on the same machine.

Weight training. The VOL group performed the same training as ES but without the superimposition of EMS. Subjects began with a warm-up consisting of 10 repetitions at 30% of MVC, 10 repetitions at 50% of MVC, and 3 repetitions of 10 seconds of submaximal isometric contraction at 90° and a 10-second resting period. Each training session consisted of 8 sets of 10 repetitions at a rate of 1:1:1 (concentric, eccentric, and resting phases, respectively) with a 3-minute rest between sets. As for ES, in each repetition, subjects moved a load equal to the 70% of their maximal voluntary contraction obtained in the pretest. The exercise pace was marked by a metronome.

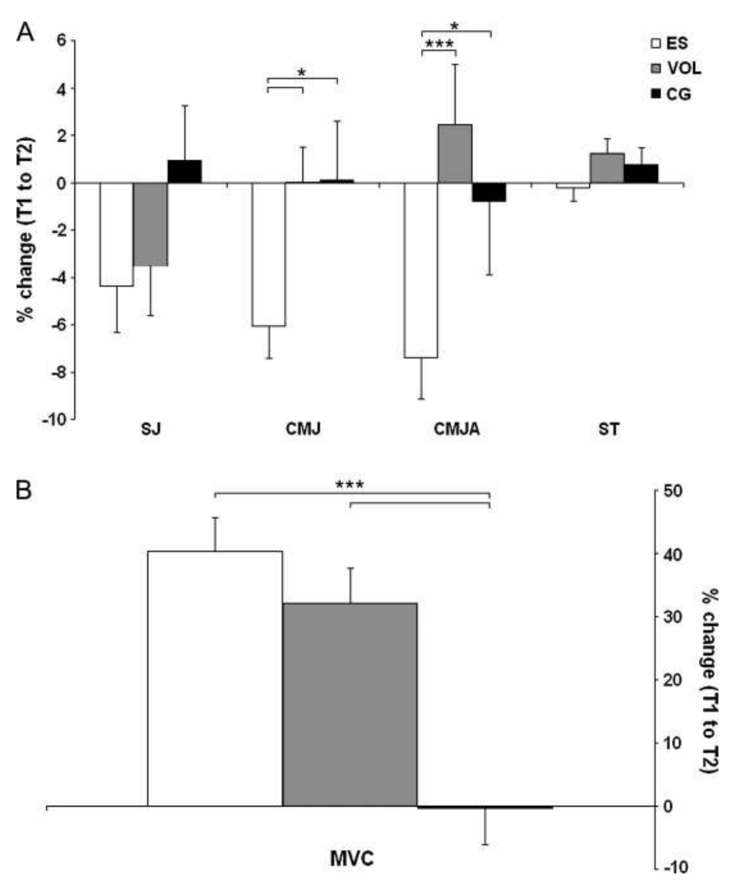

Figure 1. Percentage change in anaerobic power A) and muscle strength B) from T1 (baseline) to T2 (after training) for all the groups. See Table 1 for abbreviations. $*p < 0.05$, $***p < 0.001$.

Testing Protocols

Muscle Strength. A knee extension machine was used to assess the maximal voluntary bilateral isometric knee extension strength (MVC). A load cell (Globus Italy, Codogne, Italy) was fixed with 2 tightened chains to the resistance pad from one side and to the wall from the other (accuracy = 0.1 N). Knee angle during the test was 60°, and the resistance pad position was adapted for each individual and kept constant during the different tests. Each subject was securely strapped to the testing chair with 2 crossover-shoulder harnesses and a belt across the hip joint. The subjects were asked to cross their arms during the testing procedure and to push as hard and fast as possible and maintain the contraction for 3–5 seconds. The resting period between each maximal contraction was always 3 minutes. Three trials were completed, and the best one was used for the subsequent statistical analysis. The strength was normalized dividing the value by the weight of each subject.

Jump Testing. The subjects were asked to perform a maximal SJ, CMJ, and CMJ_A. The jumping height was calculated from flight time. The vertical jumps were carried out on a contact mat (SportJump-v1.0 System, DSD Inc., León, Spain) connected to a computer (8). Squat jump and CMJ required the subjects to keep their hands on their waist throughout the jump. Knee flexion during the jumps was selected freely by subjects (~80° of knee flexion). Three maximal attempts of each jumping modality were recorded, interspersed with approximately 20 seconds of resting period, and the peak value was used for further analysis.

Twenty-Meter Sprint Time. The sprint running tests were performed on an indoor track. The sprint running test consisted of 3 maximal sprints of 20 m, with a 120-second resting period between each sprint (7). Sprint time was recorded using photocell gates (AFR Systems®, AFR Technology, Barcelona, Spain) placed 1 m above the ground (22), with an accuracy of 0.001 seconds. The subjects started the sprint when ready from a standing position start, 1 m behind the start line. The timer was automatically activated as the subject reached the first gate at the 0-m mark. The best of 3 attempts was analyzed.

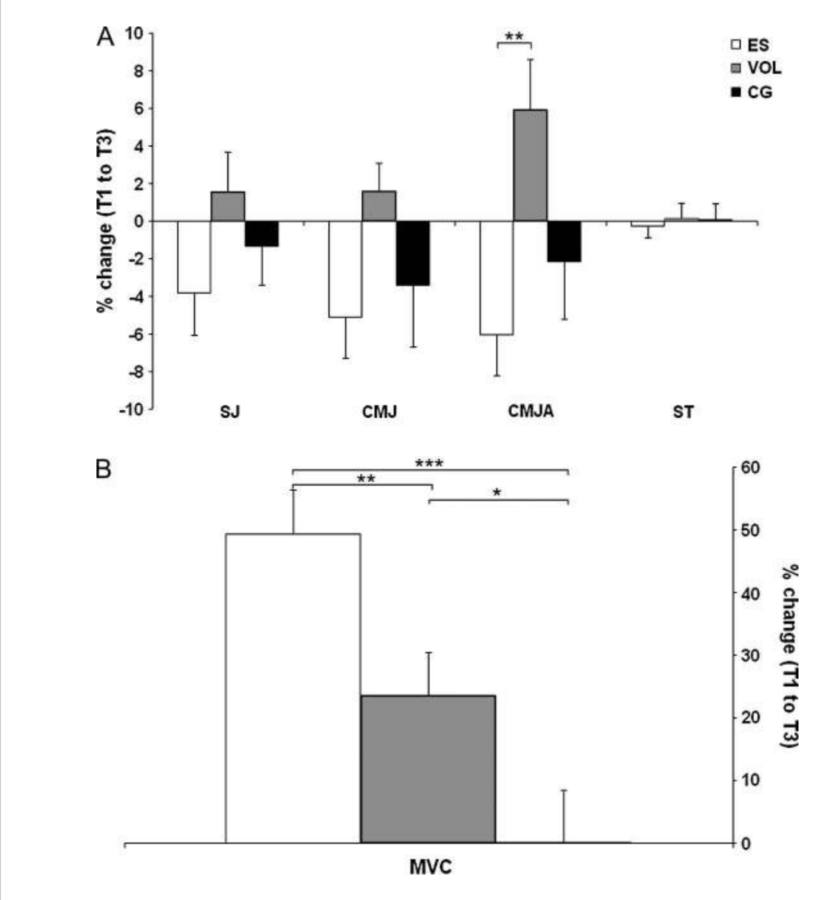

Figure 2. Percentage change in anaerobic power A) and muscle strength B) from T1 (baseline) to T3 (detraining) for all the groups. See table 1 for abbreviations. $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Statistical Analyses

Control group data were used to assess interday reliability of the dependent variables with intraclass correlation coefficient (ICC, 2.1) and coefficients of variation (i.e., $CV = SD^*100/\text{mean}$). Before the analysis, normality of the data was checked and subsequently confirmed using the Kolmogorov–Smirnov test. Likewise, group independence and homogeneity of variance were checked (1-way analysis of variance [ANOVA]) before the experimental phase. Then, a 2-way ANOVA with repeated measures on time was used to assess the effect of the training programs between the different tests (T1, T2, and T3) and the interaction of both (time × group) on the dependent variables. Another 2-way ANOVA was performed on group (ES, VOL, and CG) and percentage change (between T1 and T2 and between T1 and T3). Percentage change was calculated as follows: $(T2 - T1)^*100/T1$. When a significant F-value was achieved, pairwise comparisons were performed using a Bonferroni post hoc procedure. The level of significance was fixed at $p \leq 0.05$ for all procedures. Values are expressed as mean ± *SD* in the text and tables, and as mean ± *SE* in the figures.

RESULTS

Reliability of Measurements

Table 1 shows the CG interday reliability and variation of all the dependent variables. ICC and CV ranged from 0.817 to 0.976 and from 1.22 to 7.29, respectively.

Muscle Strength

Maximal isometric voluntary contraction values for each group and test are shown in Table 2. There was a time effect on MVC ($F = 44.5$; $p < 0.001$). Muscle strength increased from T1 to T2 (21.5%, $p < 0.001$) and to T3 (22.5%, $p < 0.001$). Likewise, there was a time × group effect ($F = 16.8$; $p < 0.001$). Group ES enhanced MVC with respect to T1 at T2 (+40.2%, $p < 0.001$) and also at T3 (+49.1%, $p < 0.001$). Something similar happened in VOL, where there was an improvement at T2 and at T3 with respect to T1 (+31.4 and +24.5%, respectively, $p < 0.001$).

Figure 1 shows that percentage change in MVC between T1 and T2 in ES and in VOL were higher than that observed for CG ($p < 0.001$). Likewise, percentage change between T1 and T3 (Figure 2) was higher in ES than in VOL ($p < 0.01$), and in both groups with respect to CG ($p < 0.001$ and $p < 0.05$, respectively).

Vertical Jump and Sprint Time

There was no time or time × group effect in any of these variables. Only a time × group effect was observed on CMJ_A ($F = 5.8$; $p < 0.001$). Thus CMJ_A had decreased at T2 (−7.5%, $p < 0.001$) for ES. This decrement remained at T3 (−5.9%, $p < 0.05$).

Observing the percentage change between T1 and T2 (Figure 1), ES changes in CMJ_A were significantly different from changes in VOL ($p < 0.001$) and in CG ($p < 0.05$). Likewise, ES changes in CMJ were greater that those observed for VOL and CG ($p < 0.05$). Analyzing the percentage change between T1 and T3 (Figure 2), ES changes in CMJ_A still remained different from VOL and CG changes ($p < 0.01$).

DISCUSSION

This is the first randomly controlled trial that compares superimposed EMS to concentric action and voluntary training performed at the same intensity. The main findings of the present study show that after training, weight work with or without superimposed EMS improved isometric muscle strength similarly, whereas they both produced no benefit on ST and vertical jump. In the case of weight training supplemented with EMS, the performance of CMJ_A was also impaired. In addition, after a detraining period, superimposed EMS training strength gains were greater than those observed with voluntary training.

The statistical treatment applied in this study revealed that both treatment groups improved their MVC alike. Some studies have found a greater increase in the biceps brachii (32) or quadriceps femoris (33) strength after superimposed EMS than those reported here. Untrained muscles as elbow flexors have a higher range of improvement than muscles accustomed to strength actions as quadriceps (5). Likewise gains in 1 repetition maximum are greater than those observed for isometric force (26). Willoughby (32,33) also showed that superposed EMS was more beneficial than weight work alone, maybe because in their studies muscles were stimulated during both concentric and eccentric phases. In the present study, muscle was only stimulated during the concentric phase so eccentric action of each repetition could be widely submaximal. In the mentioned studies, because EMS was also applied in the eccentric phase, the training load was higher; therefore, strength increases for the superimposed EMS group were higher in comparison to the voluntary training group. However, the results of these 2 studies are unusual because recently, it has been published that the superimposition of EMS in voluntary training programs does not reveal higher benefits when compared with programs performed only with voluntary exercises (23). It is generally accepted that neural adaptations predominate in short-term voluntary (27) and EMS training (9). For instance, Gondin et al. (9) observed that 4 weeks of EMS training increased knee extensors strength as a consequence of an increase in the activation level and in the RMS/M-wave EMG with no modification of structural factors. Therefore, strength gains observed after our 4-week training period could be partially attributed to neural adaptations.

Regarding the strength measurement carried out, 60° of knee flexion was selected because it has been reported to be the maximal isometric force generation angle (31), the most sensitive for strength gains (19) and the most reliable in maximum isometric force tests (24). The great reliability documented in the literature of this test, which could be considered as the gold standard for knee extensors MVC, persuaded us to avoid dynamic assessment. Also, the reliability of 1 RM in nonstrengthening subjects (29) is poorer than that observed for isometric tests (17). However, we observed a lower reliability in MVC compared with the other tests, maybe because subjects were not trained nor accustomed to resistance exercises.

Superimposed EMS did not improve anaerobic performance. Research concerning the effect of superimposed EMS training on vertical jump is very limited, and this study was the first one to investigate its effect on sprint performance. According to the results of the present study, it could be said that the application of superimposed EMS onto voluntary contraction does not produce any benefit in anaerobic performance. These actions require training concerning motor control and coordination (3), aspects that were not trained in experimental phase circumstances. Because of this, a specific and complementary work to resistance training should be done to increase anaerobic power (13). Furthermore, open kinetic chain actions were the kind of movements performed in the training sessions, whereas movements such as vertical jump and maximal sprint performance belong to closed kinetic chain actions. Accordingly, there was no specificity between training and testing conditions. Combination of concentric EMS and plyometrics should be investigated to know if both methods produce the same benefits in vertical jump as isometric EMS combined with plyometrics (13). In ES, the SJ and CMJ did not change significantly, and strength was enhanced as has been reported when the same EMS protocol was applied in isometrically (13). Because a concomitant voluntary contraction during the EMS application reduces the pain and discomfort (23), a superimposed technique should be considered to be included in training programs where strengthening is the aim.

Sprint, unlike vertical jump, requires more intermuscular coordination (14), so the dependence of the quadriceps femoris is lower than in a vertical jump. Some studies have reflected that strength training for isolated muscle groups may not be the most effective way of increasing functional abilities as sprint performance (26). Apart from this, an insignificant correlation between muscle strength and ST has been shown (6,16). Therefore, these reasons could explain why muscle strength improvements did not lead to an improvement in sprint performance. The low variability and the high reliability of anaerobic actions could be influenced by the nature of the subjects. All of them were physical education students who often perform sprints and vertical jumps. In this population, similar variability and reliability values have been reported for 20-m ST, CMJ, SJ (22), and CMJ_A (28).

Almost all the studies that analyzed EMS training effects on physical condition performed an assessment just before and after the training period. Some studies performed an assessment of what happened after the end of the training sessions, generally known as detraining (10,13,18–21). Interestingly, the present study shows that changes in MVC between baseline and detraining are higher for ES than for VOL. Then, it could be suggested that superimposed EMS onto voluntary training is more effective than voluntary training, but only after a detraining period. It has been documented that MVC improvements after an EMS training period remains above baseline levels after 2 (13), 4 (10,15), or 6 (21) weeks of detraining. Furthermore, some studies have shown that after highly demanding EMS training, a “rebound effect” may occur, resulting in enhanced MVC when training stimulus stops (13). Because EMS induced a greater metabolic demand than voluntary training (30), supercompensation probably takes more time compared with volitional training. In this study, subjects were assessed 3–4 days after the last training session. Our results show that this time was not enough for the muscle to adapt to the training stimulus. In this line, it is important to perform a detraining assessment after an EMS training session whenever possible to observe the delayed adaptations.

PRACTICAL APPLICATIONS

Superimposed EMS onto voluntary contractions increases strength more than voluntary training alone in untrained subjects; nevertheless, a detraining period should be respected to observe this delayed adaptation. Because of this, it is recommended to always perform a detraining assessment after EMS training period, because some physical qualities could be modified. An advantage of superimposed application of EMS with respect to an isometric application is that discomfort and pain during training are lower (23). On the other hand, superimposed EMS can impair vertical jump performance and has no effect on ST. Therefore, to improve anaerobic power with superimposed EMS, a complementary and specific work such as plyometrics should be carried out.

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